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PRELIMINARY RESULTS OF PLASMA MEASUREMENTS ON IMP-A

by

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-ABSTRACT-

Preliminary IMP-A plasma measurements made with a Faraday cup type instrument are presented. The main results are as follows: a) A directed flux of positive plasma ions is always observed in regions beyond the influence of the earth. b) On each satellite pass two transitions in the plasma properties are usually observed, one transition can be identified with the magnetopause and one with a shock front created by the "supersonic" plasma stream. At the subsolar point, 12:00 Hrs. typical geocentric distances to these regions are $10R_e$ and $14R_e$ respectively; on the dawn side of the magnetosphere, 06:00 hr, the corresponding distances are $14R_e$ and $23R_e$. c) In the transition region between the shock and the magnetopause a hot isotropic flux of positive plasma ions is observed.

Typical values of the directed plasma flux range from $\phi = 1.10^{8}$ cm^{-2}sec^{-1} to $\phi = 1.10^{9}$ cm^{-2}sec^{-1}. Typical values of the bulk velocity range from 250 km sec^{-1} to 440 km sec^{-1}. Data for the first three months of satellite operation will be presented and the significance of the results will be discussed.

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UNPUBLISHED PRELIMINARY DATA

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This paper presents preliminary results of plasma mea[surements] carried out with a Faraday cup instrument on the IMP-A (Explorer 18) Satellite. The sensing device measures the flux of positive plasma ions between the limits $(6 \times 10^6$ and $6 \times 10^{10})$ particles cm^{-2} sec^{-1} and over an energy range (45 to 5400)z e.v. The flux of electrons is also measured over a reduced energy range from 65 to 210 e.v.

The following characteristics of the satellite are pertinent to our discussion. IMP-A was launched Nov. 27, 1963 into a highly elongated orbit with an initial apogee of $\sim$ 31 Re (geocentric) and an initial perigee of 197 km altitude. The orbital period is $\sim$ 3.9 days. In describing the results we will use the solar ecliptic coordinate system shown in Fig. 1. In this reference frame the x axis is toward the sun; the z axis toward the north ecliptic pole, and the y axis is the third member of a right handed orthogonal set. The angles ϕ and θ respectively define the longitude measured eastward from the earth-sun line and the latitude measured in the conventional way. The initial direction of the line of apsides was in the general direction of the sun, $\theta_a = -8^{\circ}$, $\phi_a = 336^{\circ}$. Fig. 2 shows the projection of the orbit onto the ecliptic plane; from this representation one can visualize roughly the position of the satellite relative to the sun-earth line as a function of time.

The satellite was spin stabilized with a period of rotation which has remained close to 2.4 seconds; precessional motion is negligible. The initial orientation of the spin axis was $\theta_s = -50^{\circ}$, $\phi_s = 238^{\circ}$. The orientation of the spin axis as a function of time is shown schematically in Fig. 3. A further quantity of interest is the initial orientation of the orbit plane. The initial coordinates of its normal are $\Theta_n = 46^\circ$, $\phi_n = 257^\circ$.

The type of plasma sensor used on the IMP satellite is shown schematically in Fig. 4. Very briefly its operation can be described as follows: A square wave voltage which oscillates at 1 KC between the limits V_1 and V_2 is applied to the modulator grid. Particles with a ratio of kinetic energy to charge, T/z, below V_1 cannot reach the collector while those with T/z greater than V_2 are not affected by the modulating voltage. The flux of particles with T/z between V_1 and V_2 is chopped at the modulator frequency and gives an alternating current at the collector which is amplified. Filtered and compressed logarithmically into an analog output voltage suitable for the telemetry system. This type of sensor has been described in previous publications [1,2] and its operation will not be considered in detail here. The plasma sensor and its response function are axially symmetric and maximum sensitivity occurs for particles which travel parallel to the axis of the sensor. The response falls to zero about 60 degrees off axis. The effective solid angle is about one steradian and the area solid angle product is about 25 cm^2 ster.

The instrument is mounted in the satellite with its axis of symmetry at right angles to the spin axis. Thus, as the satellite rotates the sensor scans a 360 degree field which extends $\pm$ (60°) with respect to the equatorial plane of the satellite. The telemetry format which governs the operation cycle is shown in Fig. 5. The format consists of four sequences each lasting 82 seconds. Each

1. Bridge, Dilworth, Rossi and Scherb, J. Geophys. Res. 65, (1960) 3053
2. Bright, Lazarus, Lyon, Rossi and Scherb, Space Research III, North Hdland Publishing Co. (1963) 1113.

82 second sequence is divided into 16 equal frames 5.1 seconds in duration. One sequence in four is devoted exclusively to the rubidium magnetometer; during the remaining three sequences six 5.1 second intervals are alloted to the plasma measurements. The cycle of plasma measurements always begins in sequence 1 after the rubidium magnetometer measurement and is as follows: sequence 1, positive ions $T/z = (45 - 105)$ e.v. and $T/z = (95 - 235)$ e.v.; sequence 2, positive ions $T/z = (220 - 640)$ e.v. and $T/z = (560 - 200)$ e.v.; sequence 3, electrons $T = (65 - 210)$ e.v. and positive ions $T/z = (1700 - 5400)$ e.v. Approximately 3.5 seconds of each 5.1 second measurement interval is available to transmit the plasma signal. During this time the output is sampled every 160 m.s. corresponding to equal angular intervals of approximately 20°. These 22 measurements require about 1.5 revolutions. The energy window is then shifted and the process repeated. A complete energy scan requires 2.8 minutes and is repeated every 5.5 minutes.

At this point we summarize briefly the main results obtained to the present writing, and, in what follows, we give a more detailed description of the experimental evidence.

The main results are as follows:

a) A directed flux of plasma ions is always observed in regions far from the earth where the plasma motion is unaffected by the geomagnetic field. We refer to this as region I.

b) For each orbit at least two transitions in the properties of the plasma are observed on the inbound pass and on the outbound pass of the satellite. One transition can be identified with magnetopause and one with a shock front created by the supersonic plasma stream. At the subsolar point, 12:00 hours, typical geocentric distances to these regions are $10R_e$ and $14R_e$ respectively; on the dawn side of the magnetosphere, 6:00 hours, corresponding distances are $14R_e$ and $23R_e$.

c) Between the shock front and the magnetopause, region II, a hot isotropic flux of plasma is observed.

In Fig. 6 the plasma flux is plotted on a linear scale as a function of rotation angle for the 5 positive ion levels and for the electron level. These data were taken on orbit 1 when the satellite was at a distance of 21.7 R_e. It is clear that the signal is concentrated in energy window 3, (220-640)z e.v., and that the plasma flow is essentially unidirectional. The arrows on the figure indicate the time at which the axis of the sensor pointed as closely as possible to the sun. Within the angular uncertainty of $\pm 10^\circ$ it is clear that the longitude of the bulk velocity vector ϕ_v is 180°. Data which should permit the simultaneous determination of θ_v has not yet been reduced. The signals plotted in Fig. 6 are characteristic of region I.

In Fig. 7 the general plot is similar to that shown in Fig. 6; the data refers again to orbit 1, but the distance was 15 R_e. It is clear that the angular distribution is essentially flat and that the energy spectrum extends from the lowest to the highest channel. (The noise level in Figs. 6 and 7 is about 6×10^6 cm^{-2} sec^{-1}).

To permit a more ready inspection of the data we have chosen to plot appropriate 2.8 minute averages of the plasma properties every 5.5 minutes. A portion of such a plot for orbit 3 inbound is shown in Fig. 8. The abscissa is a linear time scale increasing to the right.

From top to bottom the first line represents the average energy flux per particle with the ordinate in e.v.; in the second graph the ordinate represents $\log_{10}$ of the total position ion flux; the third graph represents the $\log_{10}$ of the electron flux, and finally the fourth graph gives a measure of the width of the energy distribution. For the proton and electron fluxes two values are computed: one "looking toward" and one "looking away" from the sun. Thus two levels are seen plotted for these fluxes in Fig. 8 and the separation between the maximum and minimum flux level is a measure of the anisotropy of the plasma flux. In the figure the proton flux at distances greater than $15R_e$ has a value of $\sim 10^8$ cm^{-2} sec^{-1} and shows a high degree of anisotropy. The electron flux at this time is essentially at the noise level of the instrument. These conditions are characteristic of those we have identified with region I and persist until about $15R_e$ At this time the thermal energy of the protons increases, and the flux becomes close to isotropic. At the same time a relatively large flux of isotropic electrons is observed. These conditions are characteristic of region II and persist with some variations until about $10R_e$ when there is an abrupt decrease of the proton and electron fluxes to the noise level. In this pass $10R_e$ corresponds to the boundary of the magnetosphere. The space within the magnetosphere is defined as region III.

The data in Fig. 8 were obtained during orbit 3 when the satellite was close to subsolar region. With the exception of 3 passes which have not yet been examined, similar results have been obtained for 43 traversals of the boundary region (up to orbit 23, Feb. 24). These data are plotted in Fig. 9; the solid lines indicate the portions of the orbit in which the flux observed was essentially isotropic. (Fig. 2 is useful in interpreting this figure). In constructing the figure, points on the trajectory have been rotated about the earth-sun line into the plane of the ecliptic.

The most striking feature evident from Fig. 9 is that the shape of the magnetospheric boundary and the shape of the shock front are in full agreement with the well known theory of supersonic aerodynamic flow around a blunt body. On the average at least, regular boundary surfaces are observed for the magnetosphere and the shock front during an extended period of time. This observation suggests that a stable boundary surface exists. There are, however, features of the data which are as yet unexplained and the details of the interaction between the plasma and the geomagnetic field are as yet not obvious. Initial attempts to check the conservation equations for particle density, momentum flux and energy density across the shock transition are encouraging and results will be reported in due course. Finally, we would like to emphasize that rapid transitions in the properties of the plasma are a characteristic feature of the data.

This can be seen by a close inspection of Fig. 9. In this representation broken regions of the orbit traces indicate regions in which a transition was observed from a nearly isotropic flux of positive ions to a directed flux. Typically conditions change in the following sequence on an inbound pass: I $\rightarrow$ II $\rightarrow$ I $\rightarrow$ II.... $\rightarrow$ III. Transitions between these conditions are observed to take place in times less than 5 seconds and the time during which region I is observed in the sequence II $\rightarrow$ I $\rightarrow$ II is frequently of the order of 5 or 10 minutes. For this reason, the transitions tend to be "washed out" by the 2.8 minute averages used in Fig. 8. Fig. 10 shows a portion of the orbit in which data for the maximum and minimum flux observed during one revolution of the satellite is plotted for energy level 3 (220 - 640) e.v. Transitions between regions I and II are clearly evident. Detailed spectra for a transition of this sort are as shown in Fig. 11. Here the transition has taken place with a time uncertainty of ~ 80 seconds defined by the magnetometer sequence which occurs between the two plasma measurements shown.

We acknowledge with gratitude the close and effective collaboration with our many colleagues at the Goddard Space Flight Center. Without their help, this work would not have been possible.

In the analysis of the data we have profited by the work of Dr. G. Moreno and by discussions with Prof. S. Olbert; Mr. R.H. Baker of Lincoln Laboratory contributed in an essential way to the design and construction of the experiment.

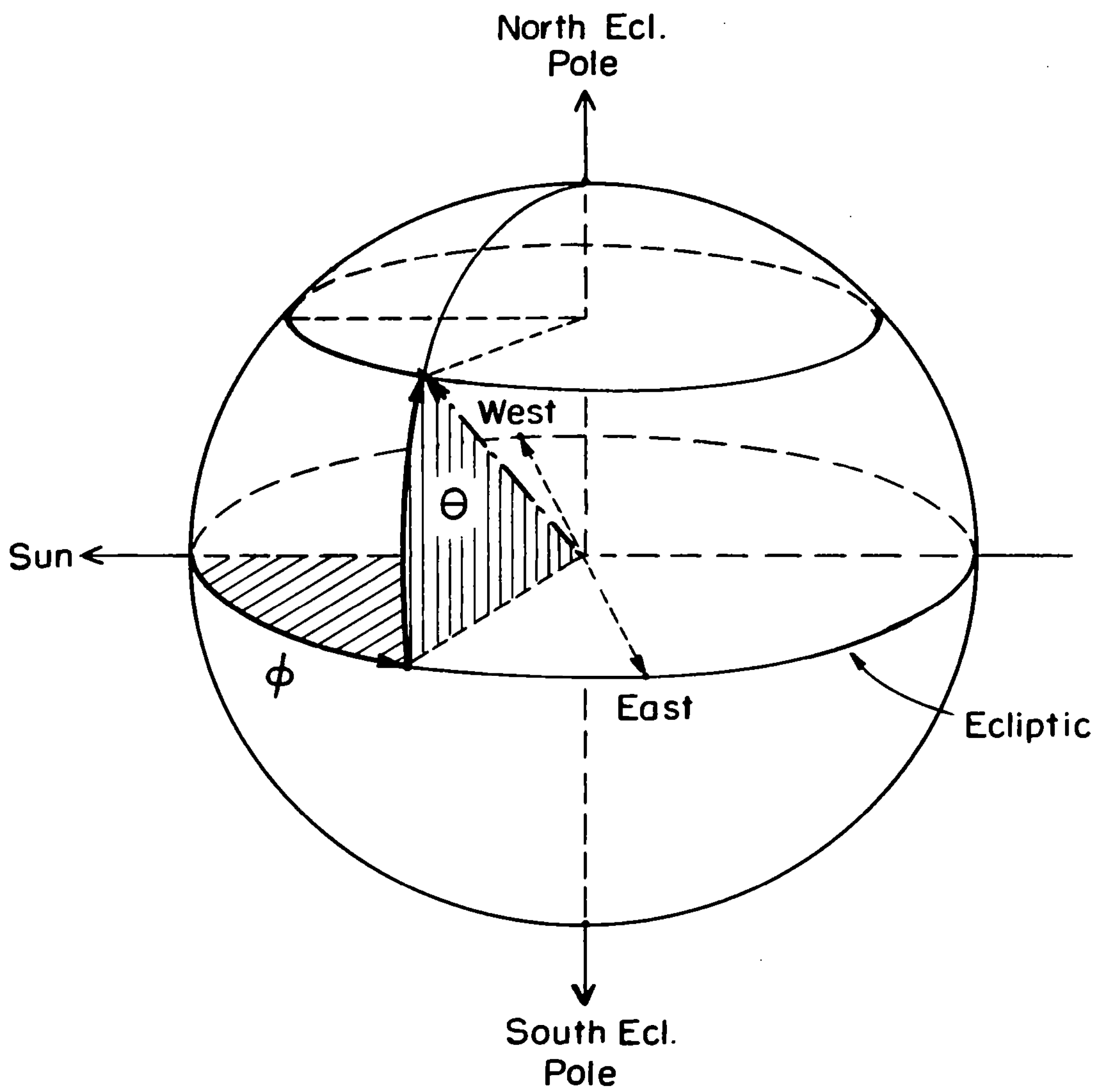


Fig. 1

IMP I ORBIT-EARTH - SUN RELATIONSHIP

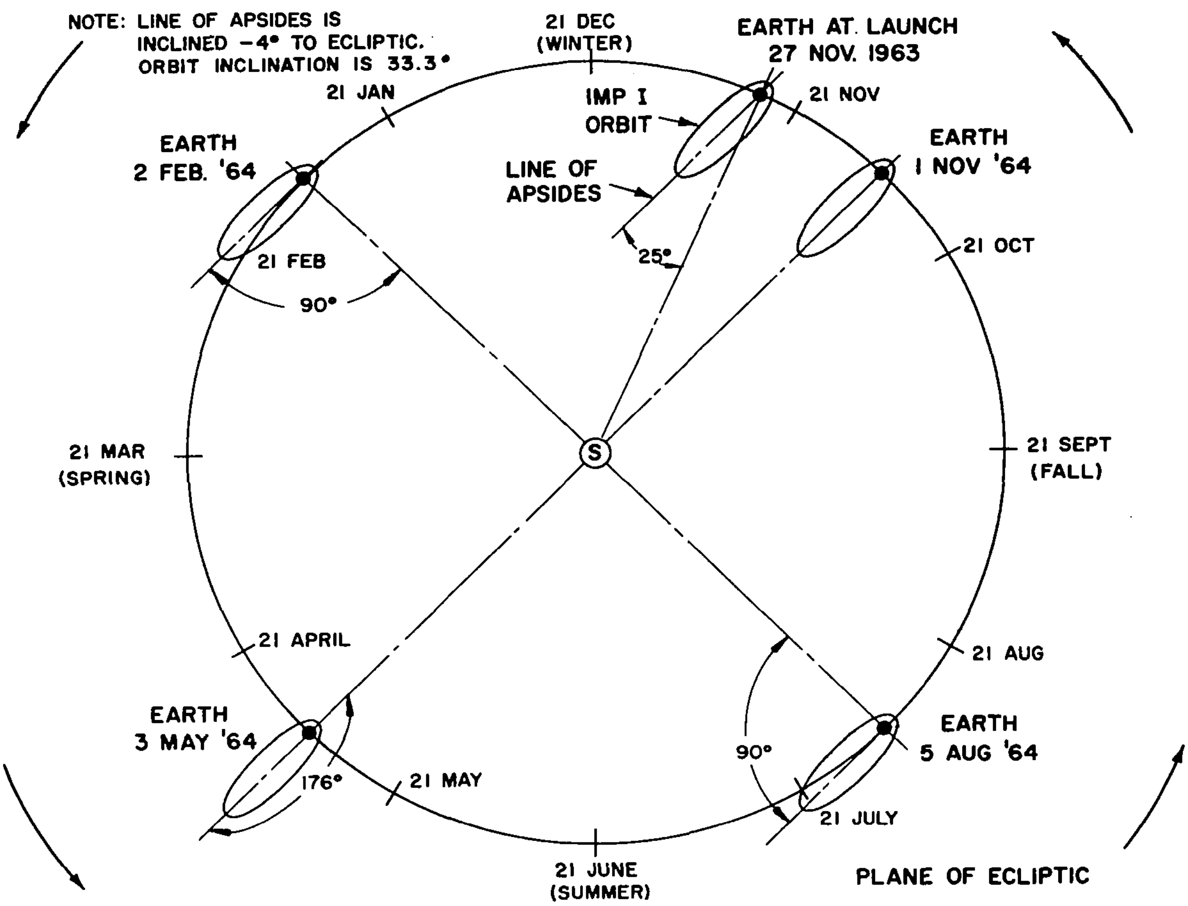


Fig. 2

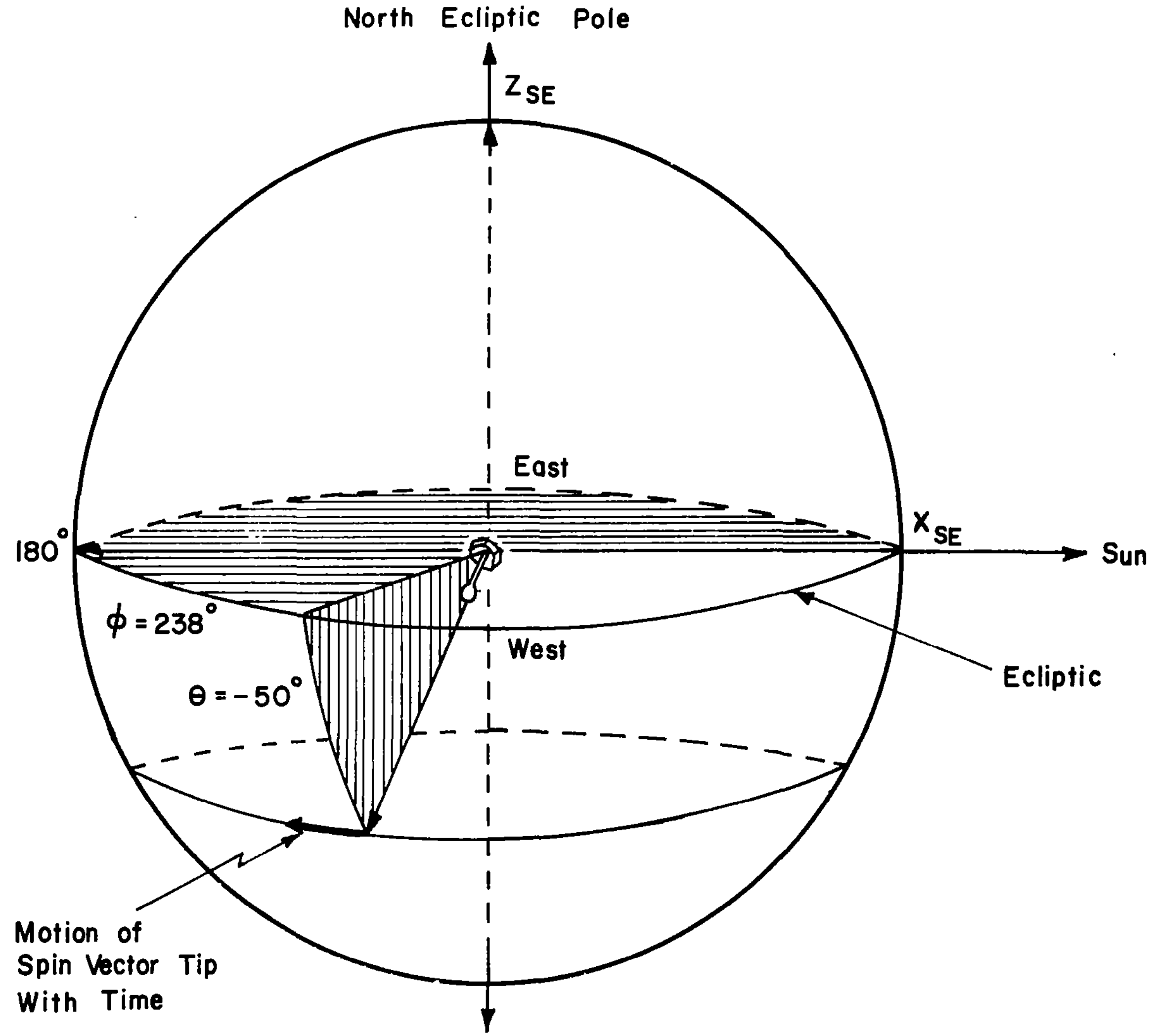


Fig. 3 - ORIENTATION OF SATELLITE AT TIME OF LAUNCH
(NOV. 27, 1963)

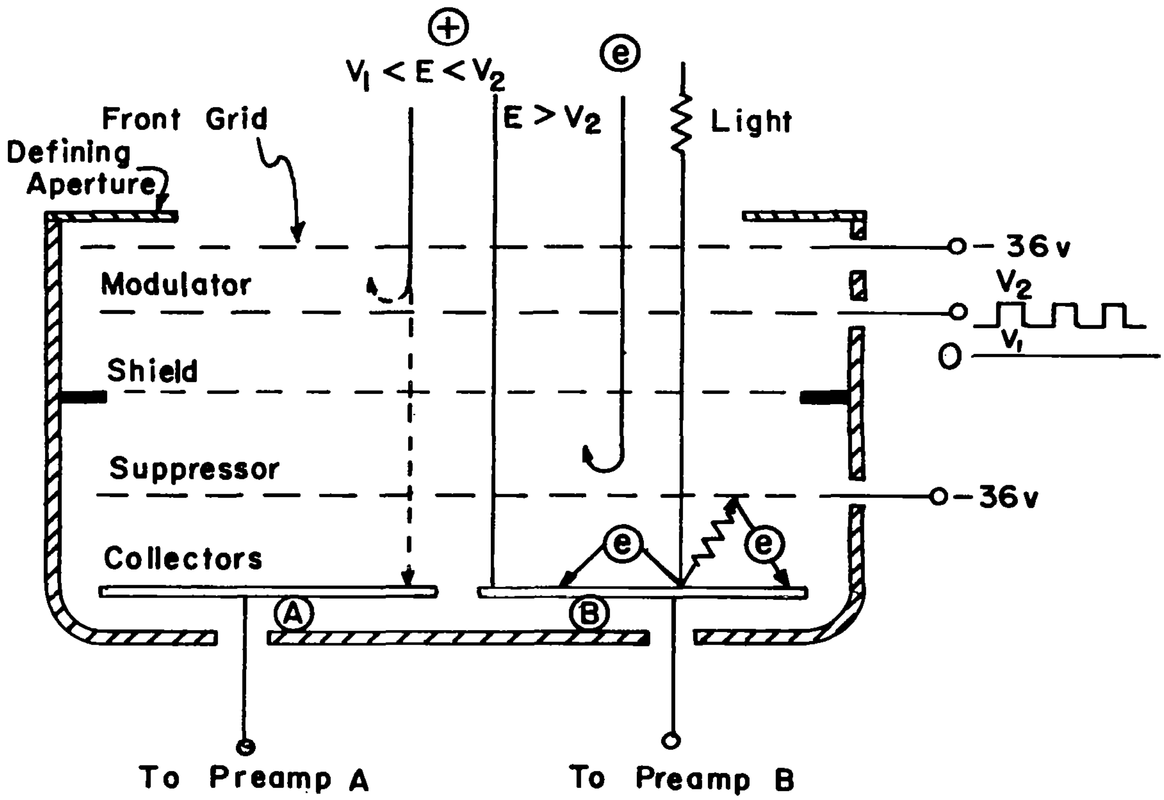
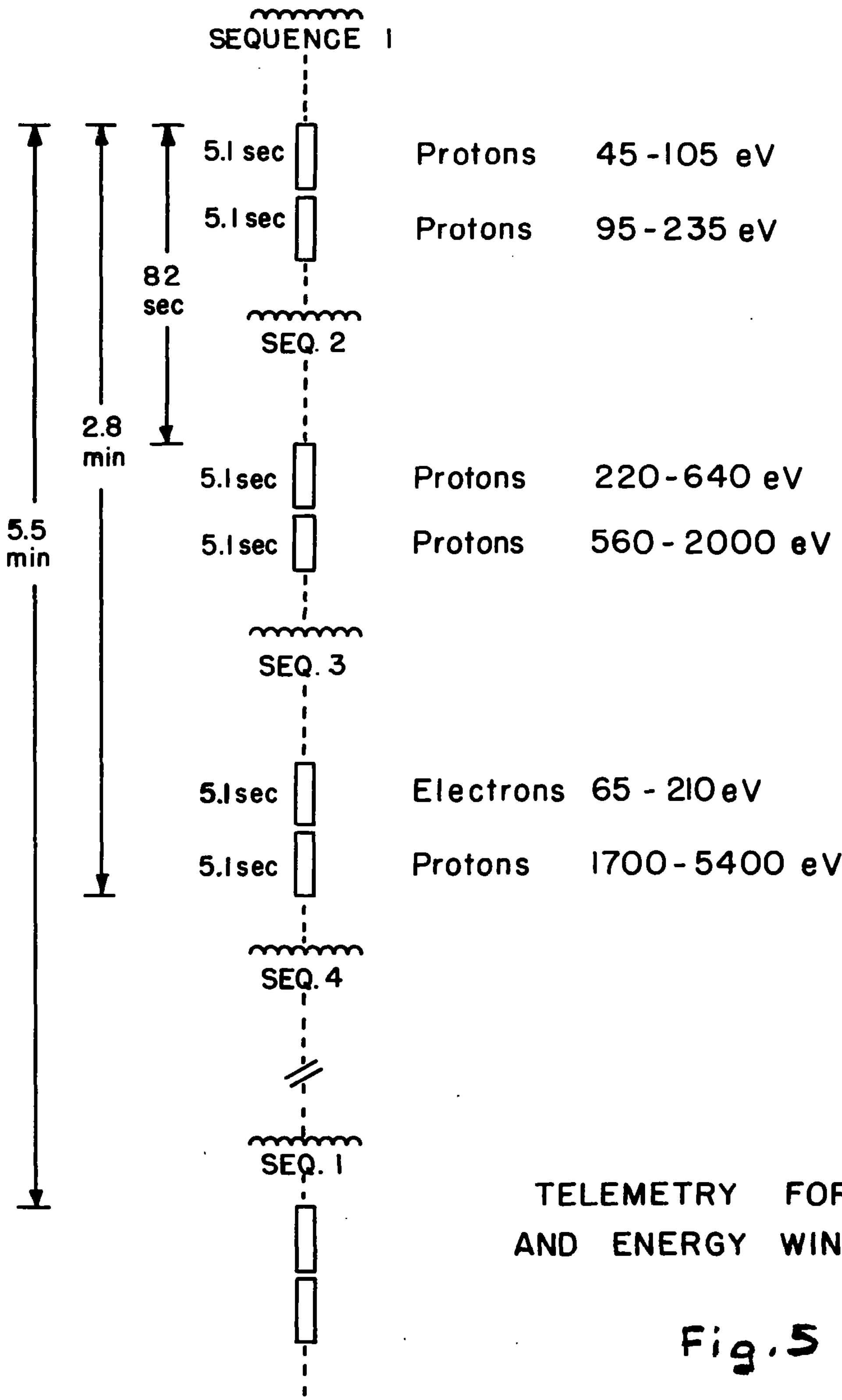


Fig. 4 - IMP-A PLASMA CUP



TELEMETRY FORMAT AND ENERGY WINDOWS

Fig. 5

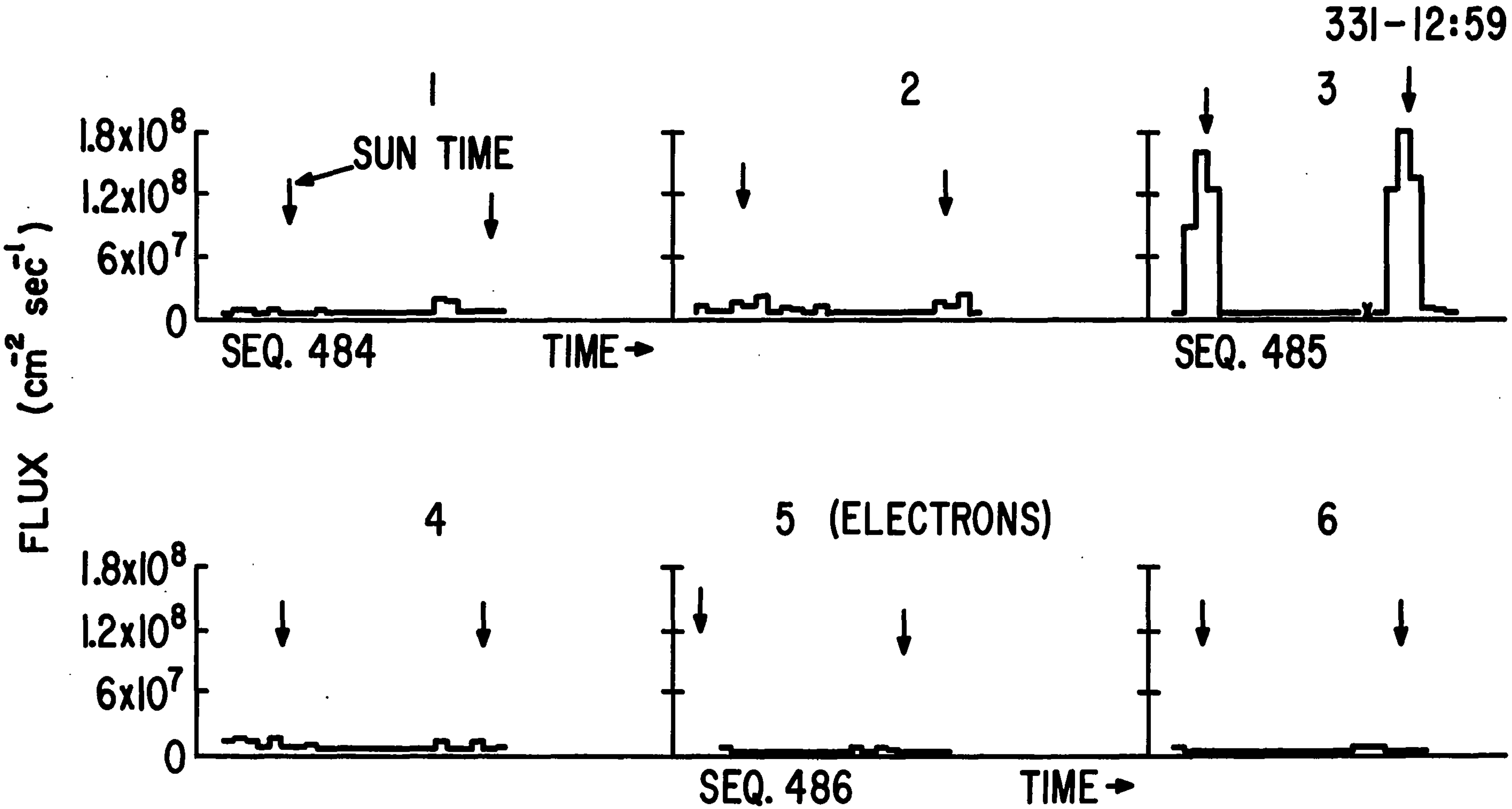

331-12:59
1
2
3
1.8x10^8
1.2x10^8
6x10^7
0
SUN TIME
FLUX (cm^-2 sec^-1)
SEQ. 484
TIME →
SEQ. 485
4
5 (ELECTRONS)
6
SEQ. 486

Fig. 6

331-10:48

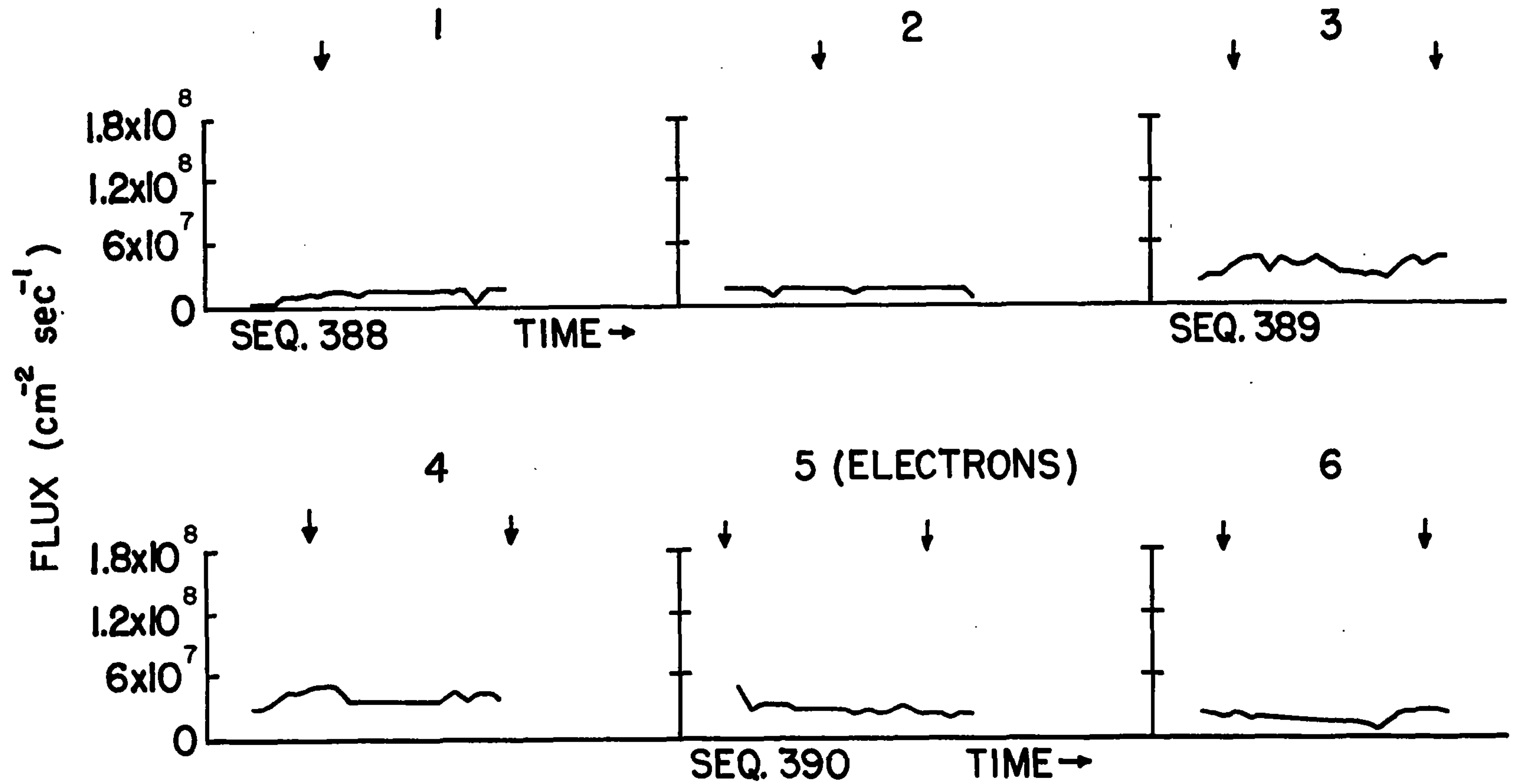
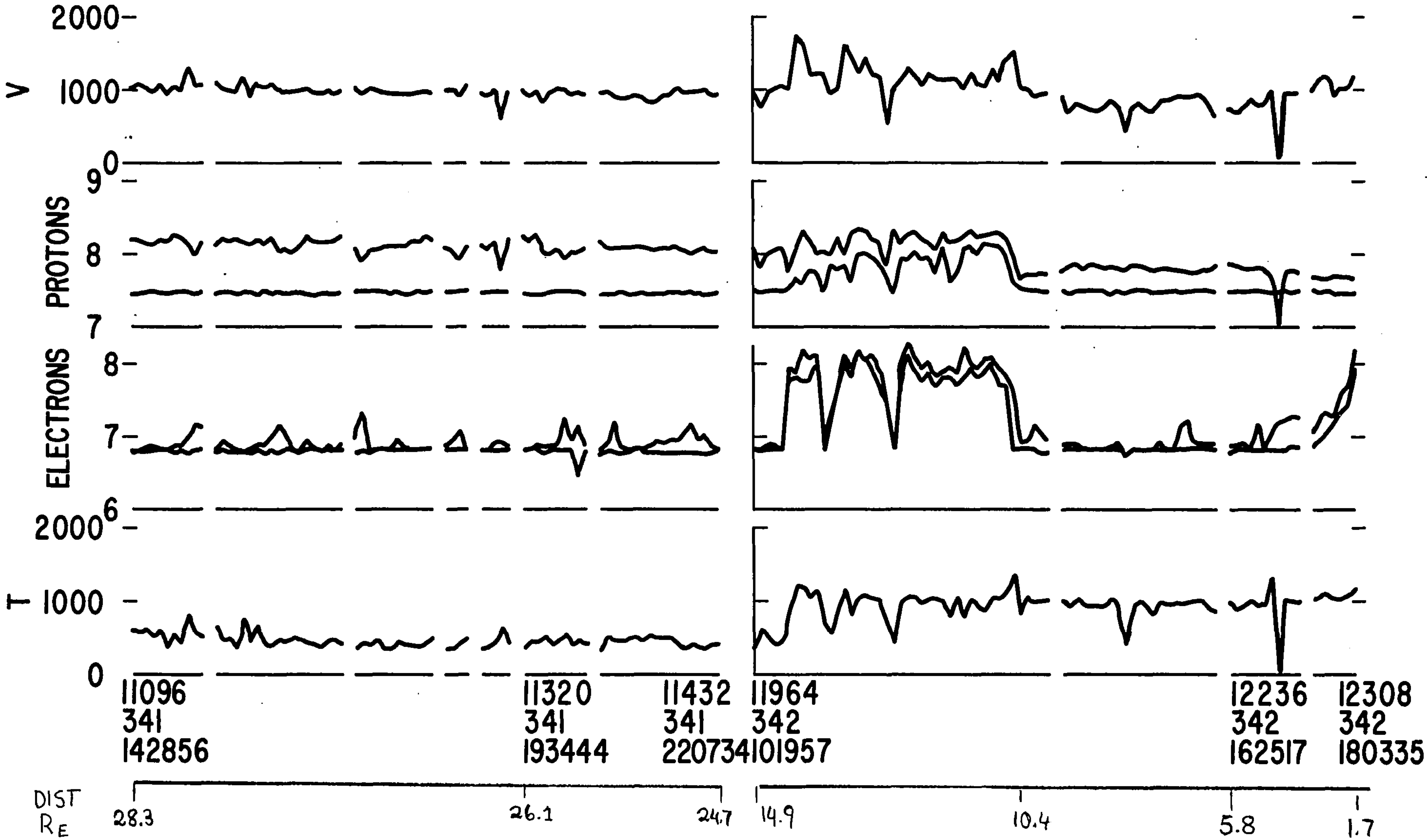
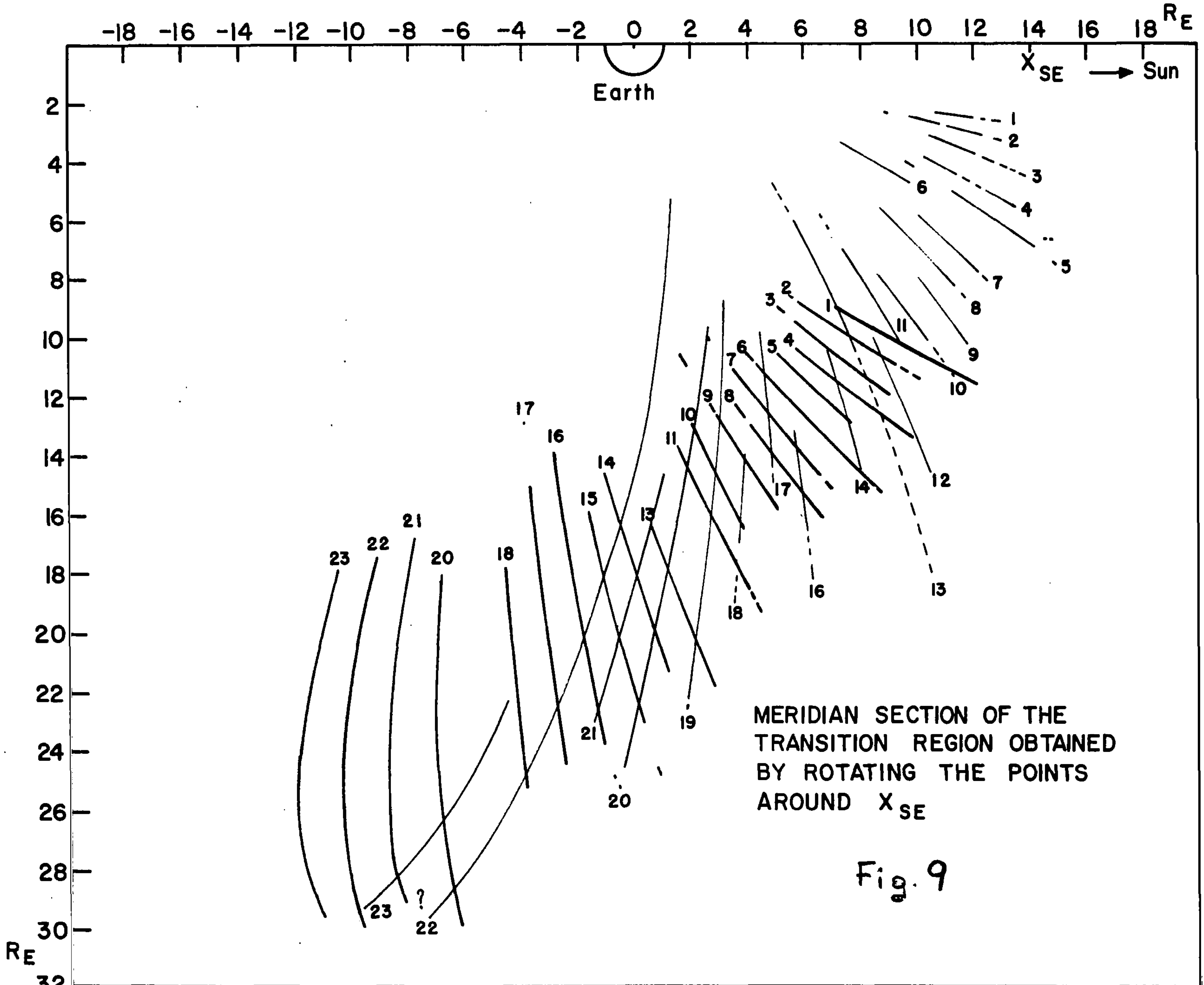


Fig. 7



V
2000
1000
0
PROTONS
9
8
7
ELECTRONS
8
7
6
T
2000
1000
0
11096
341
142856
11320
341
193444
11432
341
220734
11964
342
101957
12236
342
162517
12308
342
180335
DIST
R_E
28.3
26.1
24.7
14.9
10.4
5.8
1.7

Fig. 8



-18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 R_E
Earth
X_{SE} → Sun
R_E
MERIDIAN SECTION OF THE TRANSITION REGION OBTAINED BY ROTATING THE POINTS AROUND X_{SE}

Fig. 9

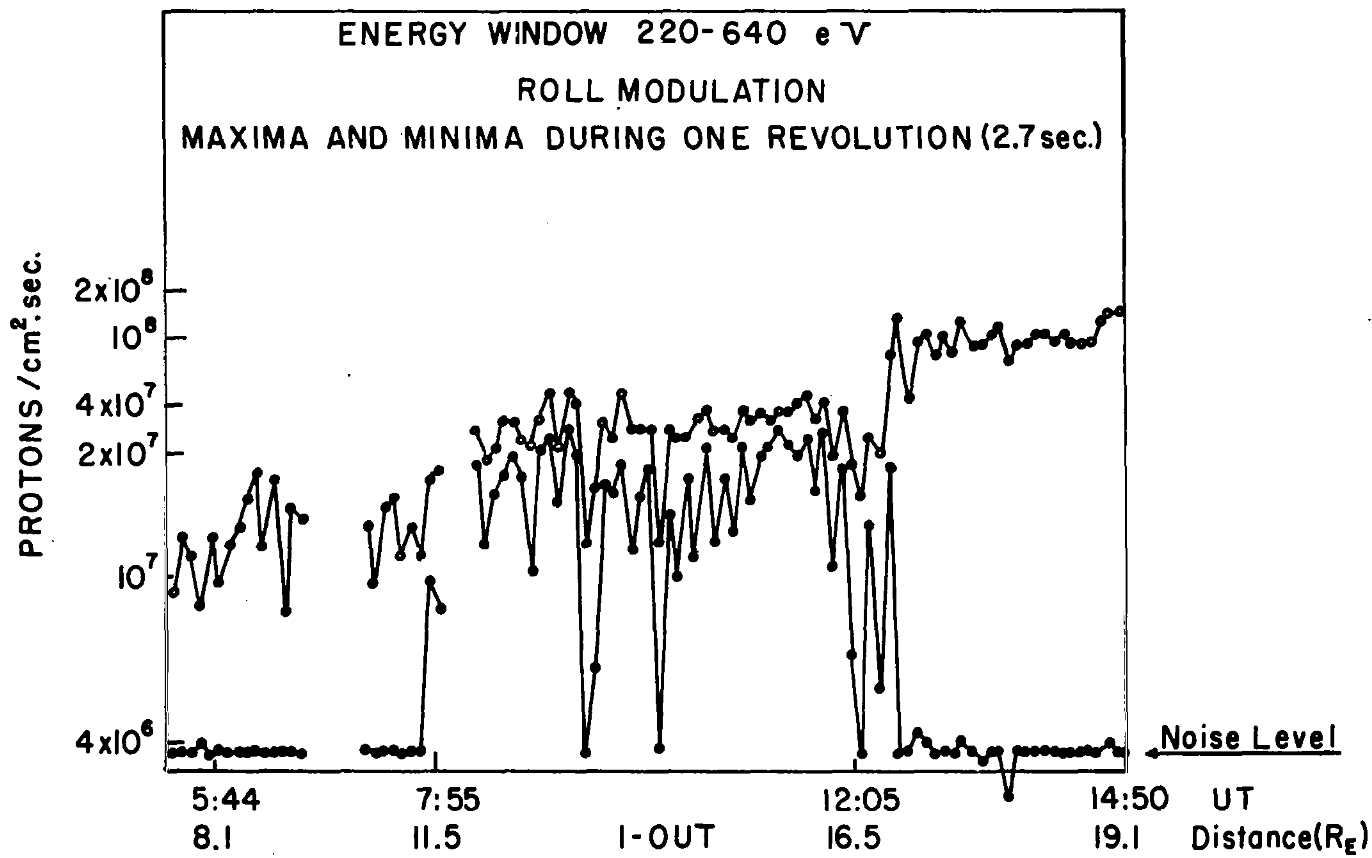


Fig.10 - IMP I- 1st PASS OUTBOUND (NOV. 27th, 1963)

Fig. 11

ORBIT I INBOUND - DIST. 13.1 R_E — NOV. 30, 1963 (DAY 334)
TRANSITION FROM REGIME I TO REGIME II